Barrier RF Stacking

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Outline

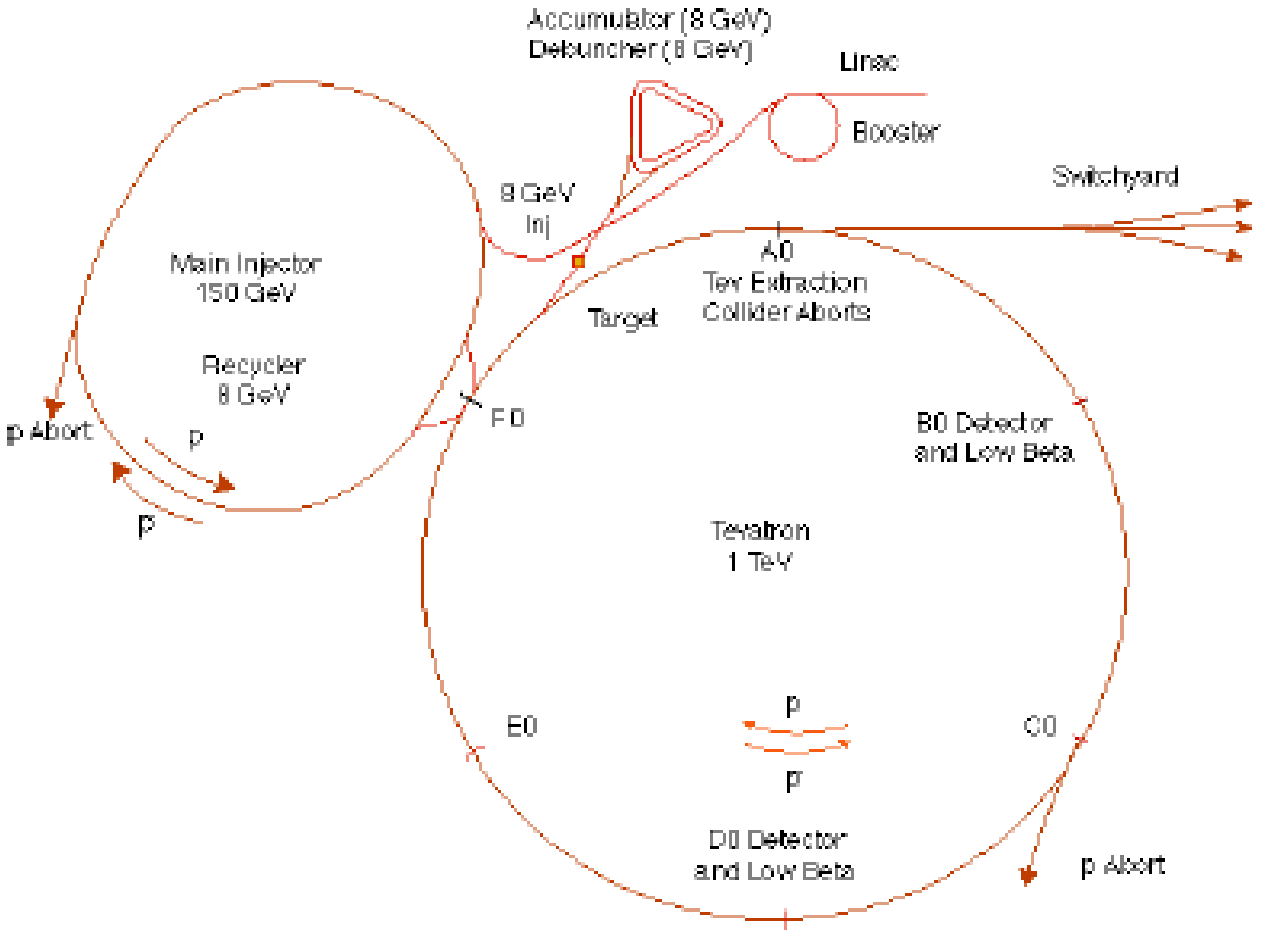
- Motivation and goals
- Introduction of the method
- Hardware requirement and specs
- Summary

http://www-bd.fnal.gov/pdriver/barrier/

Motivation

- To increase the Tevatron luminosity in Run2 by increasing the proton intensity on the pbar production target (2 x 1 Booster batch)
- To increase the neutrino flux in NuMI experiment by increasing the proton intensity on the pion production target (2 x 6 Booster batches)

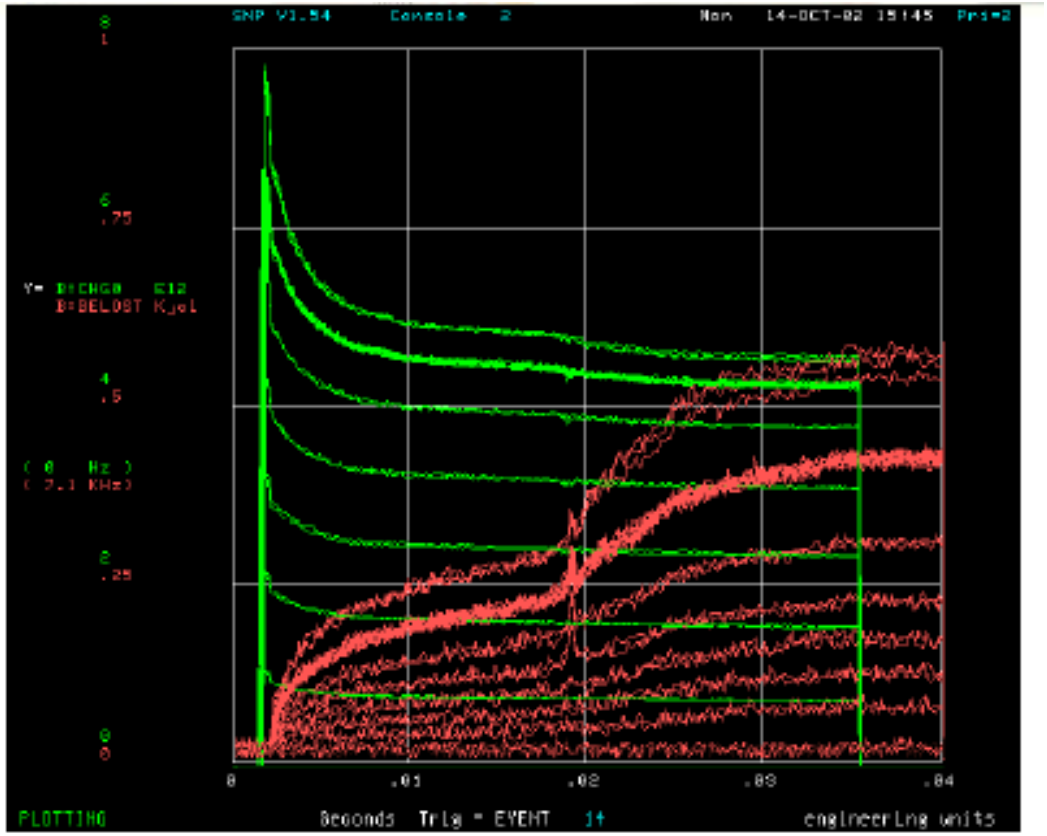
Fermilab Accelerator Complex



Bottleneck - Booster

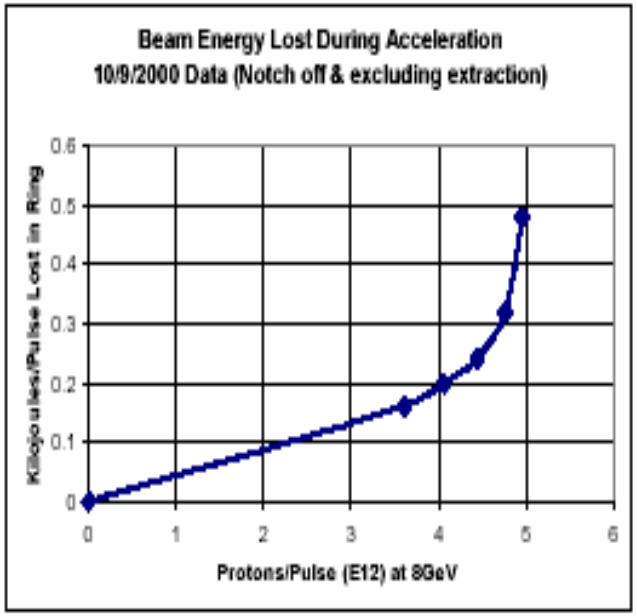
- The Booster is a bottleneck limiting the proton beam intensity in the Fermilab accelerator complex.
- The Linac can provide 3e13 particles per cycle
- The Main Injector with moderate upgrade can accept 3e13 protons per cycle
- However, the Booster can only accept and deliver 5e12 particles per cycle

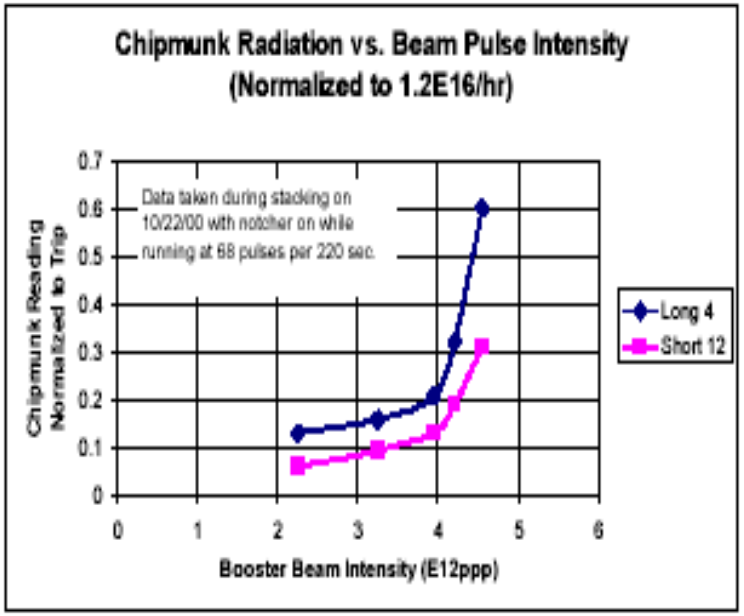
Booster Beam Loss



For 0, 2, 4, 6, 8, 10, 12, 14 Injected Turns

Booster Energy Loss





Solution - Stacking

- A solution is to stack two Booster bunches into one Main Injector RF bucket
- This is possible because the Main Injector momentum acceptance (0.4 eV-s) is larger than the Booster bunch emittance (0.1 eV-s)

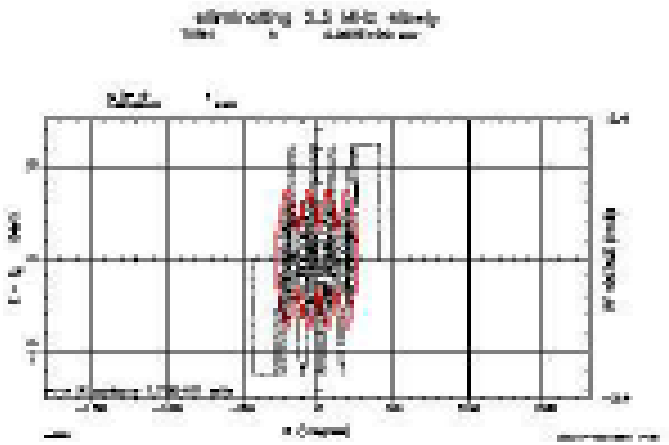
Stacking Goals

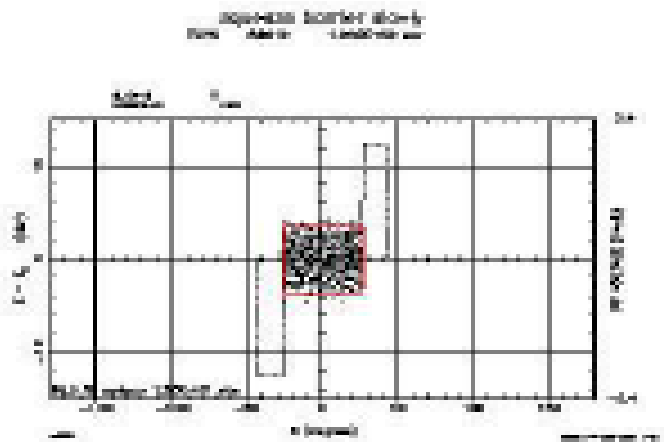
- Goal for Run2 – To increase protons per second (pps) on the pbar target by 50%
  - Present: 4.5e12 every 1.467 sec
  - Goal: 2 x 4.5e12 every 2 sec
- Goal for NuMI – To increase pps on the NuMI target by 60%
  - Baseline: 3e13 every 1.867 sec
  - Goal: 2 x 3e13 every 2.333 sec

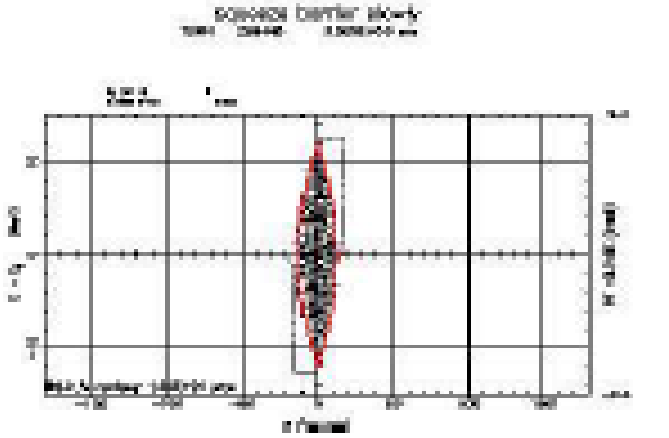
Method

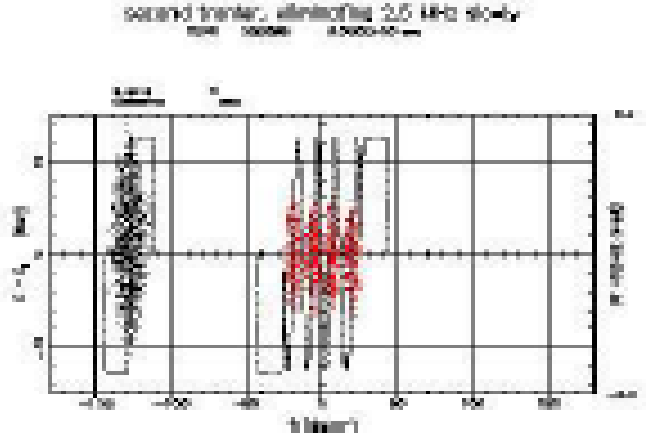
- A straightforward way is to inject two Booster batches into the MI, confine them by RF barrier buckets, then move the barrier to compress the beam.
- But the compression must be slow (adiabatic) in order to avoid emittance growth. This would lengthen the injection process and thus reduce protons per second (pps)
- A better way (first proposed by J. Griffin) is to inject Booster batches off-axis so that the injection can be continuous

Injection Beam On-Axis
(Recycler, courtesy C. Bhat)

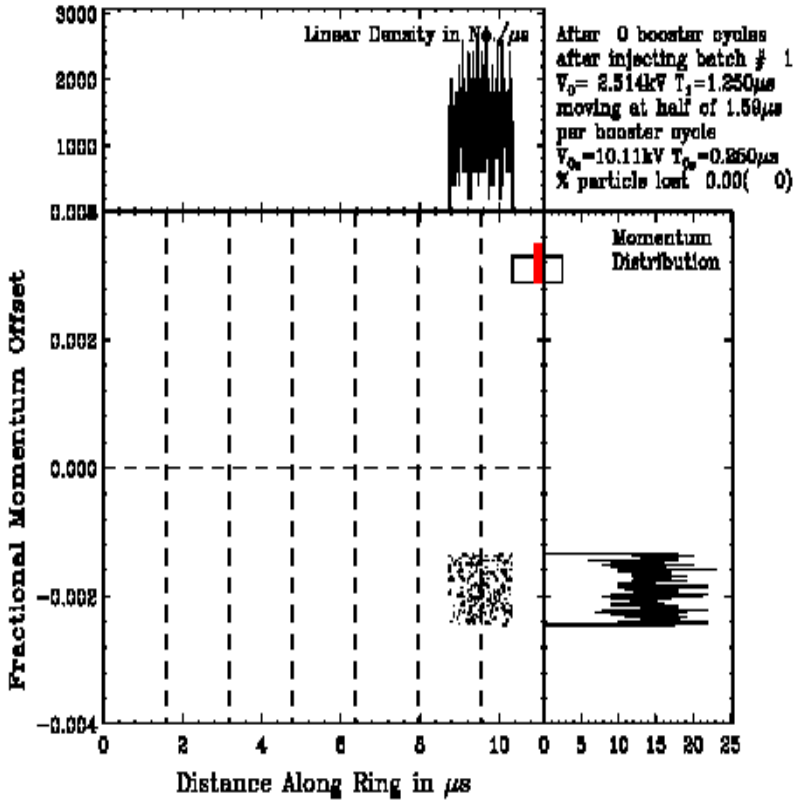


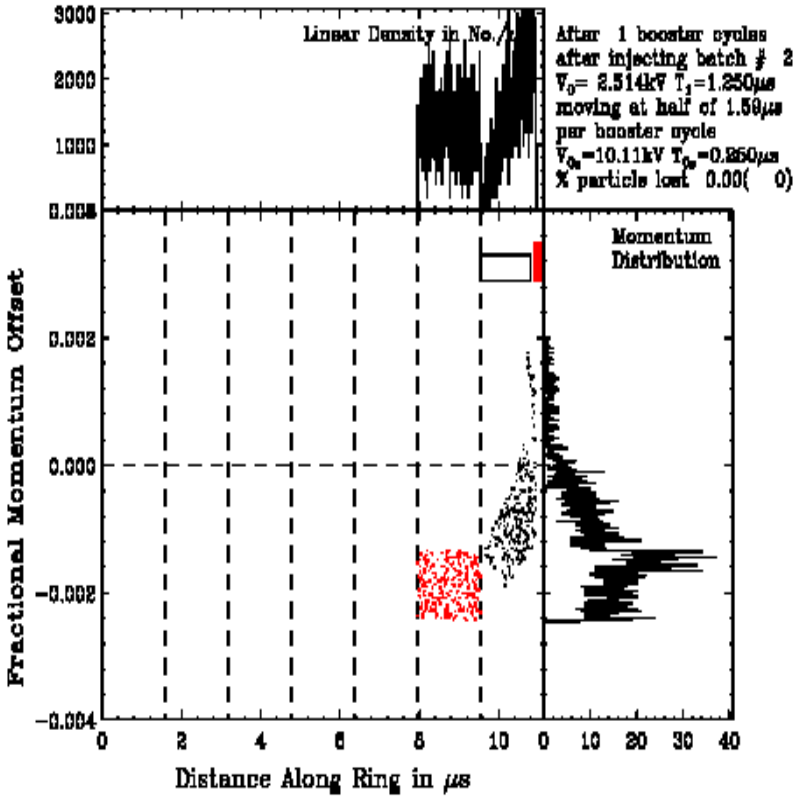




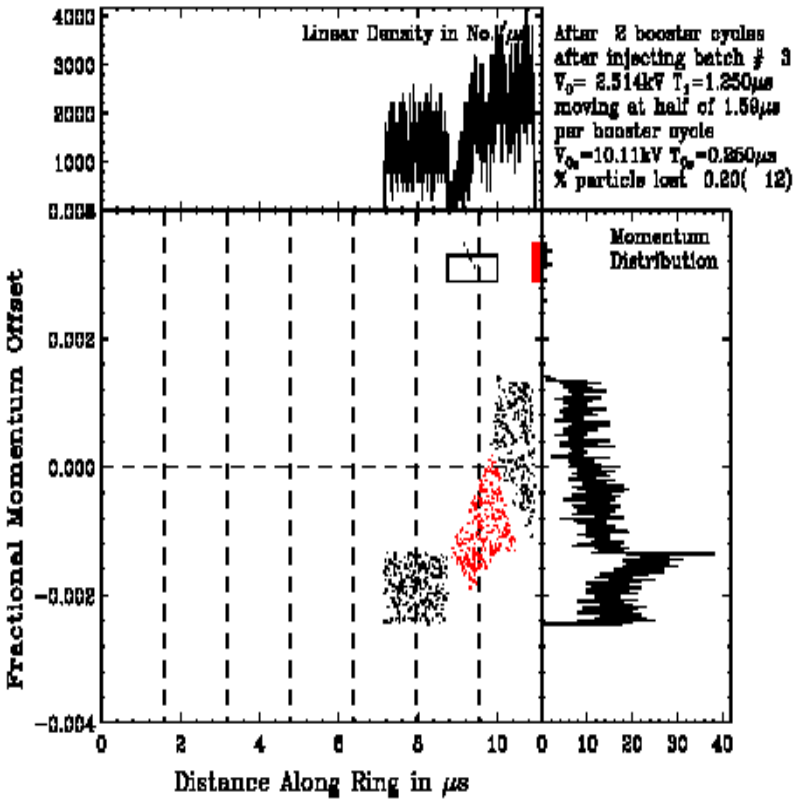


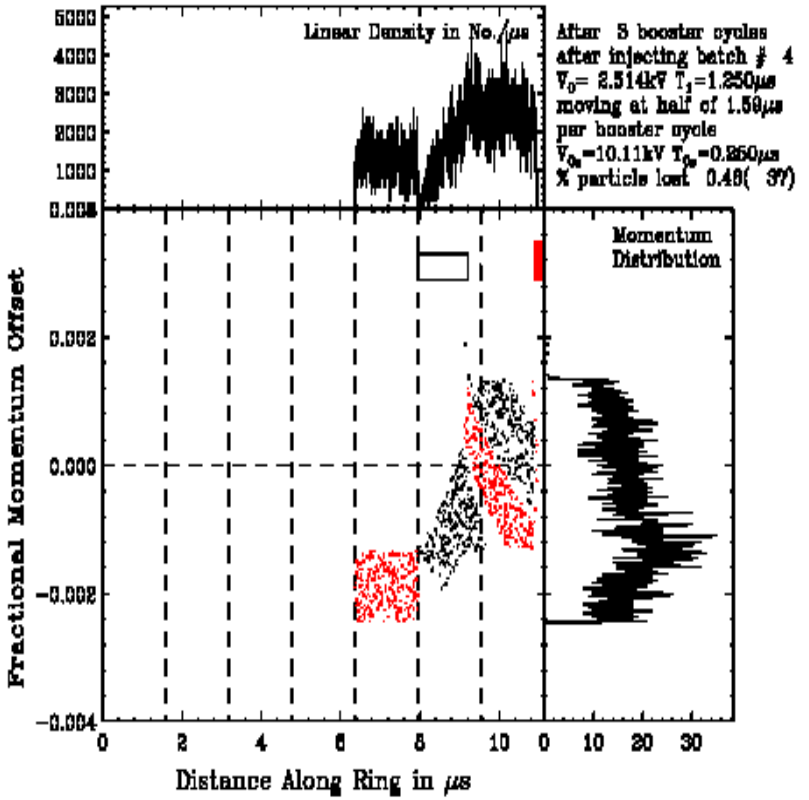
Injection Beam Off-Axis
(12-batch stacking, courtesy K-Y. Ng)





12-Batch Stacking (cont…)





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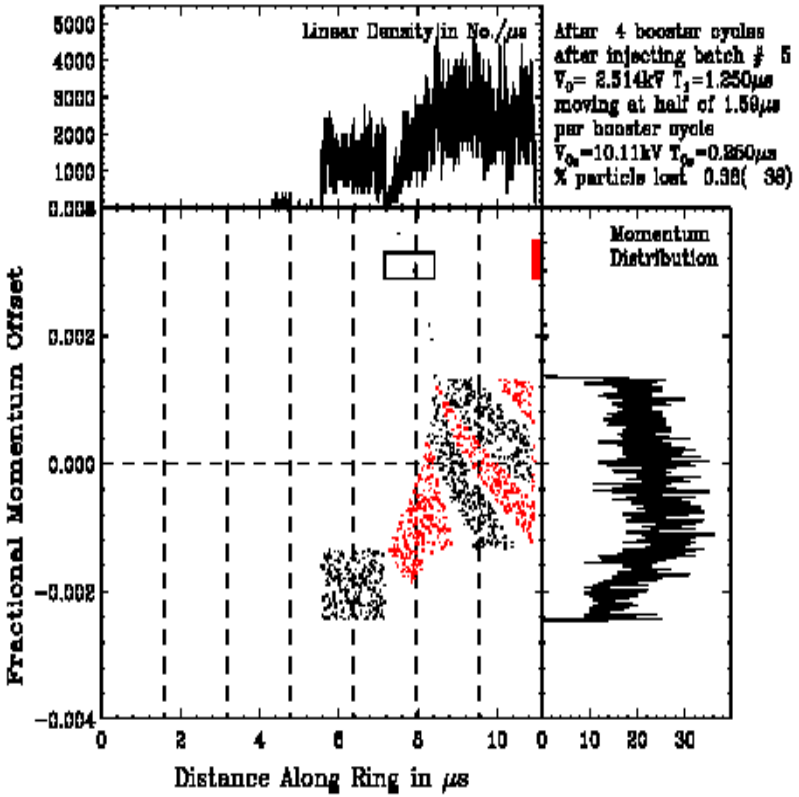
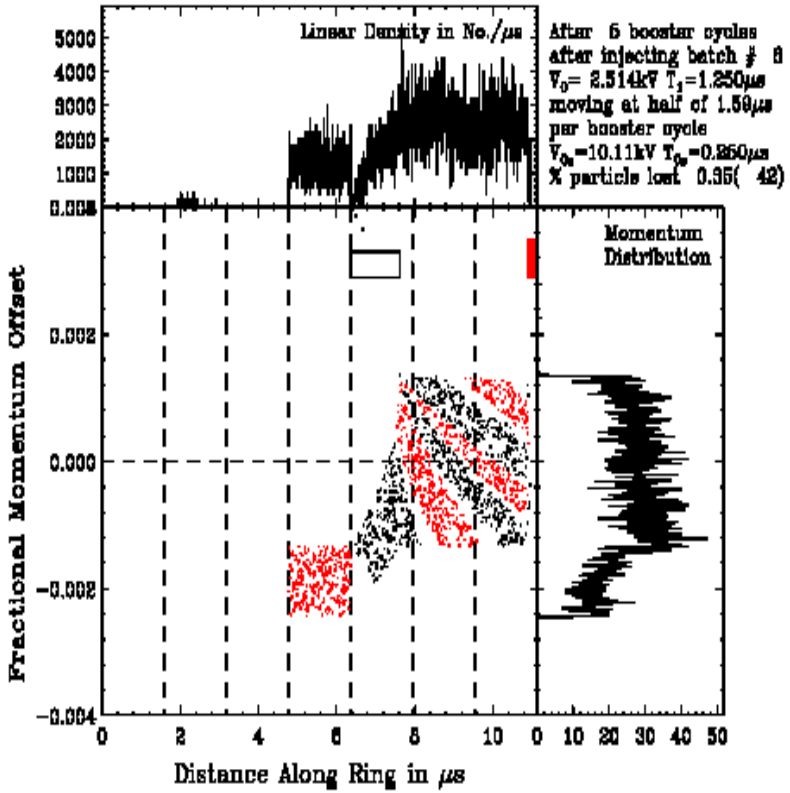
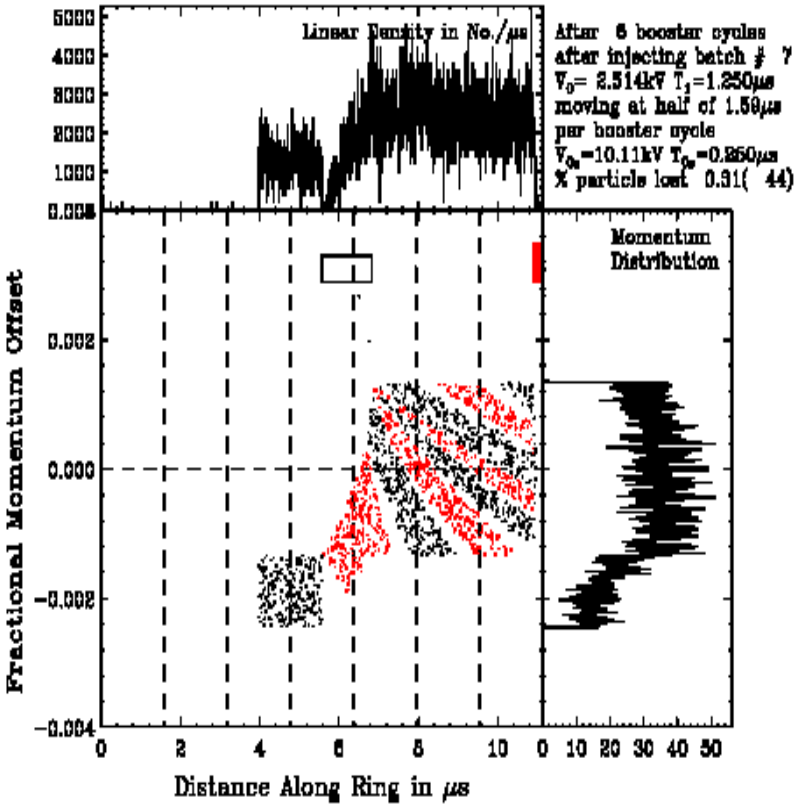
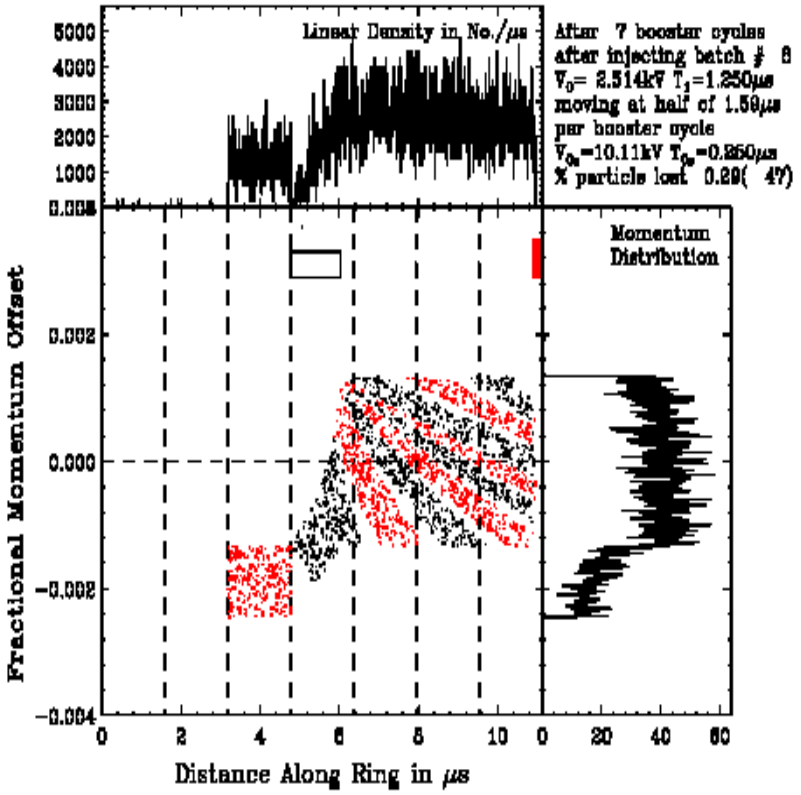




12-Batch Stacking (cont…)





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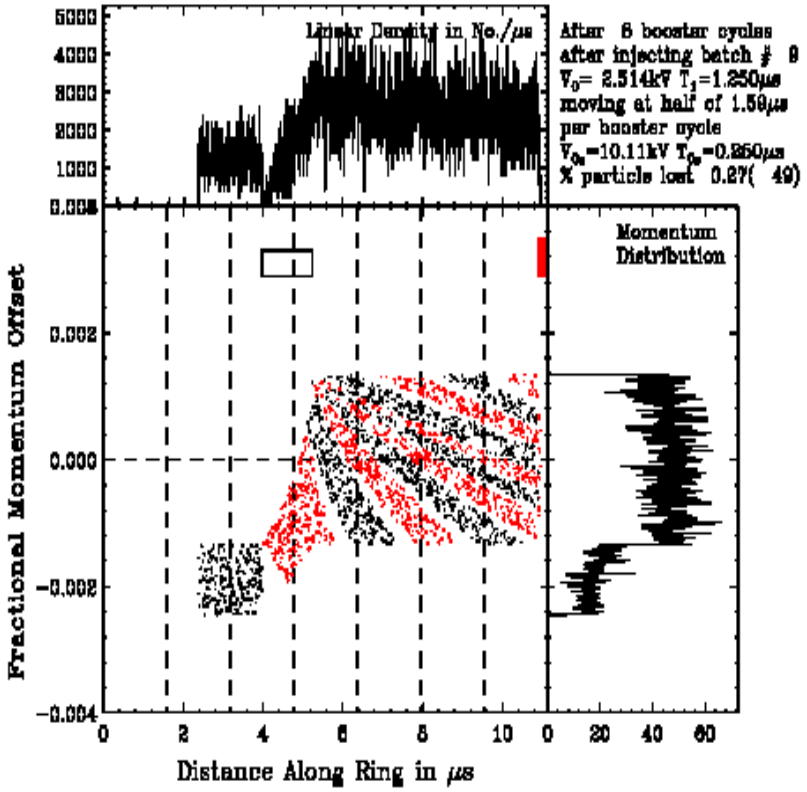
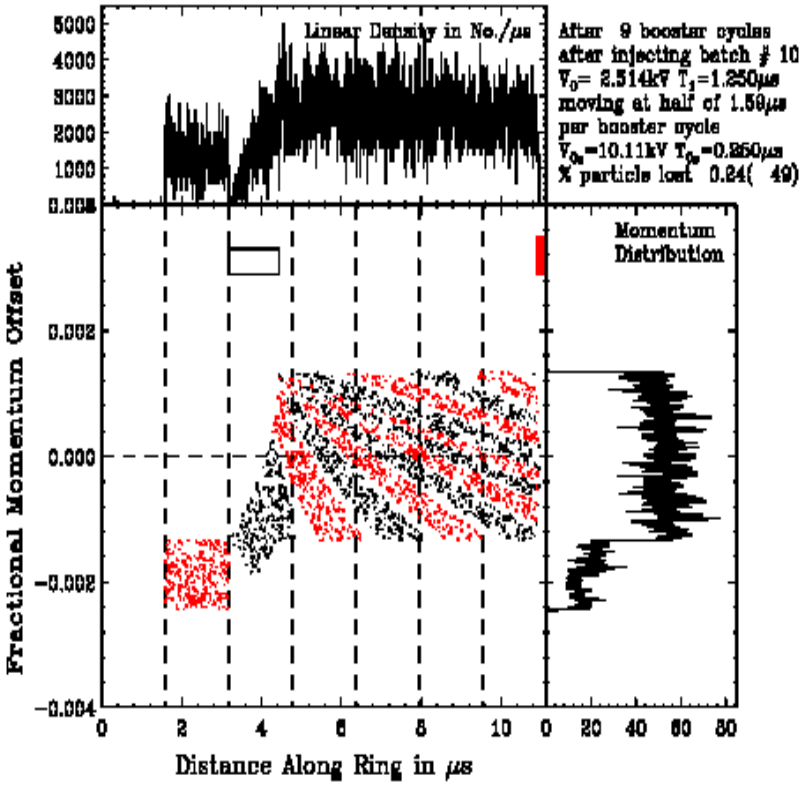
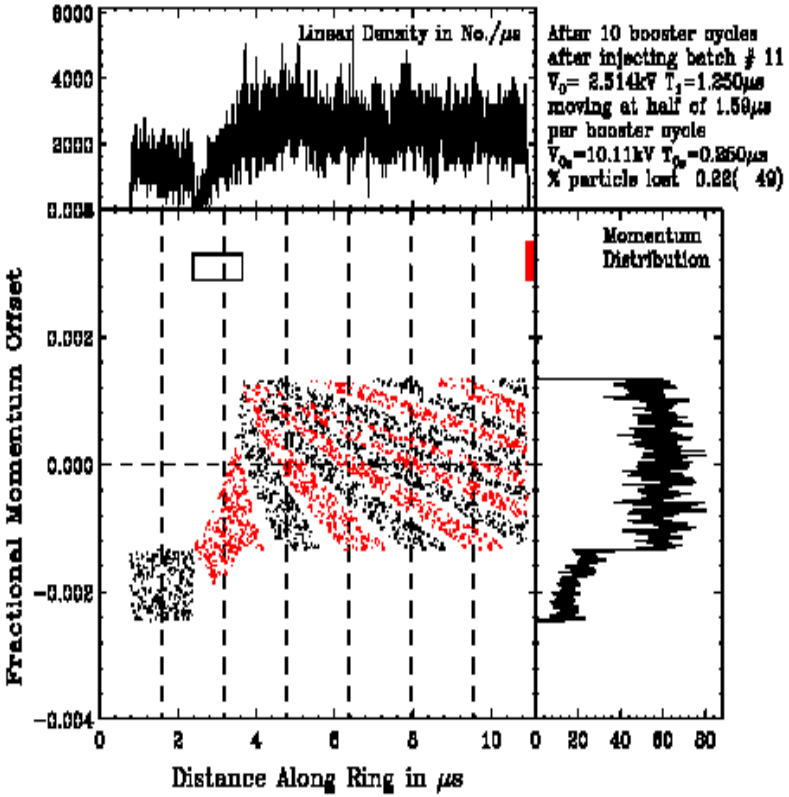
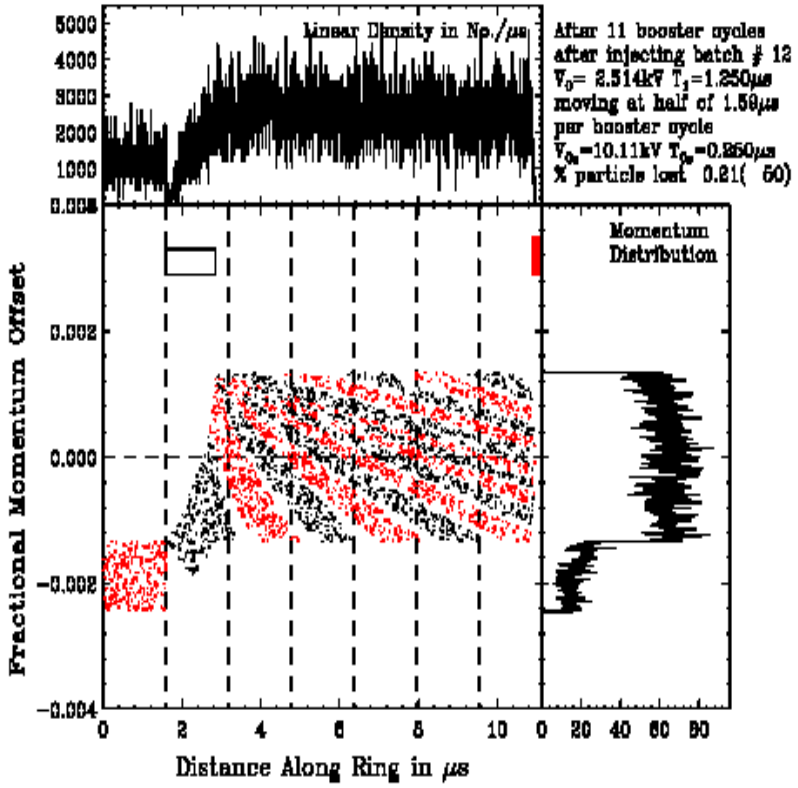




12-Batch Stacking (cont…)





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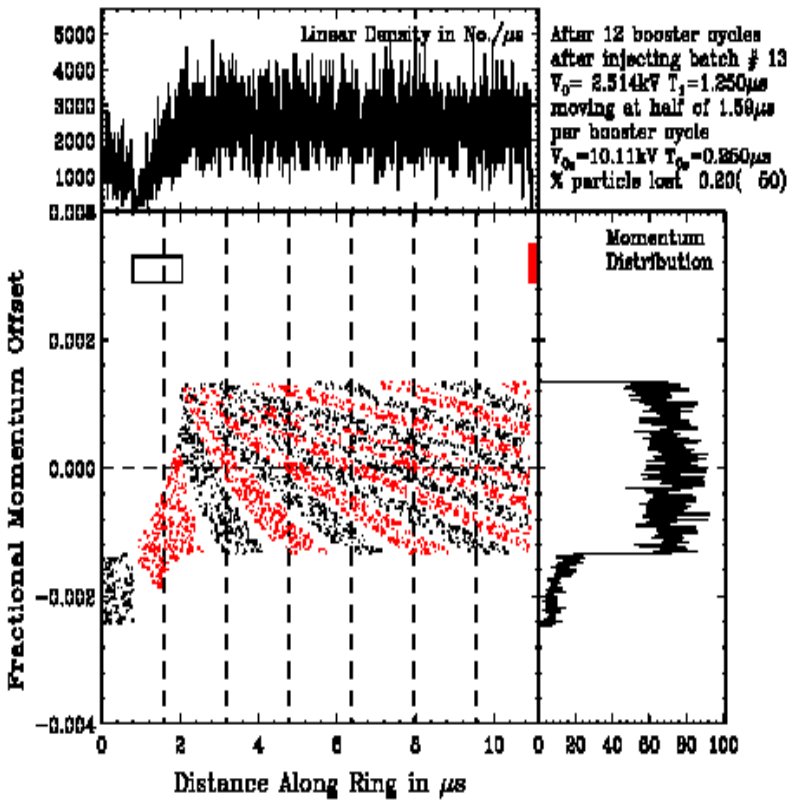
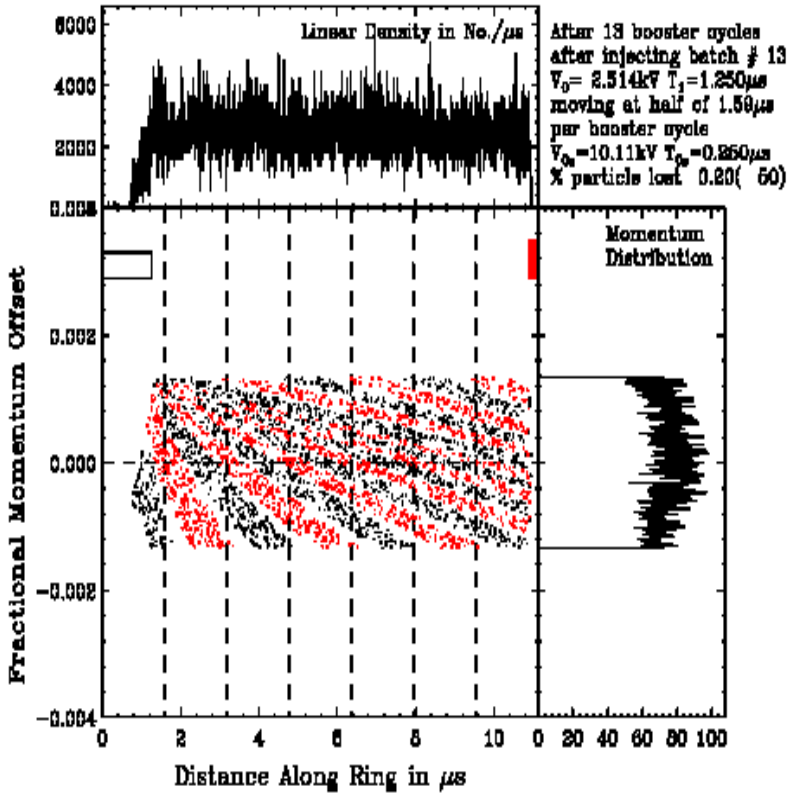
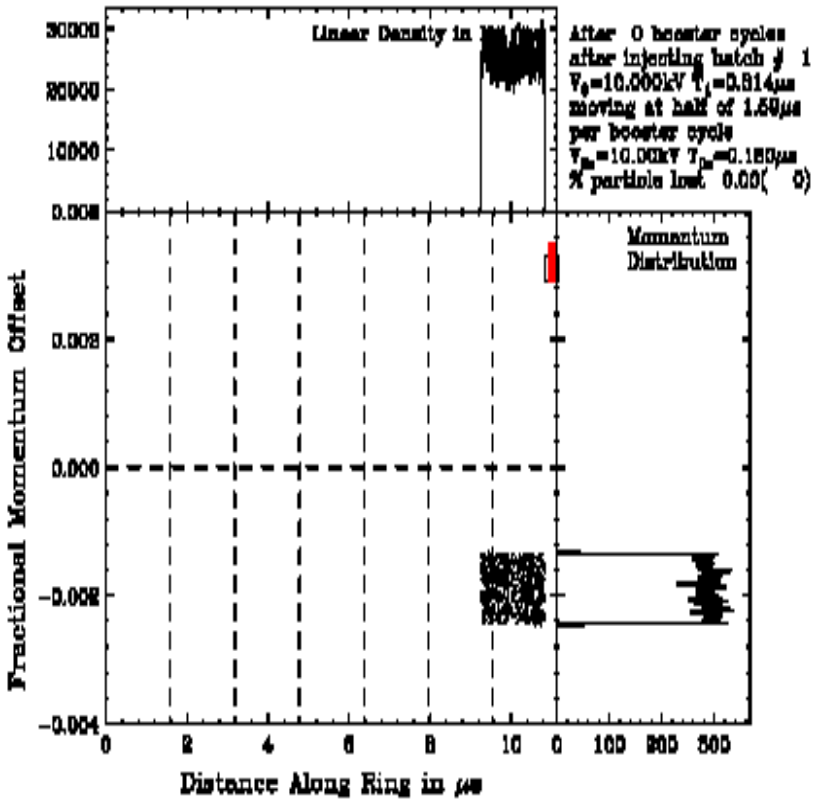
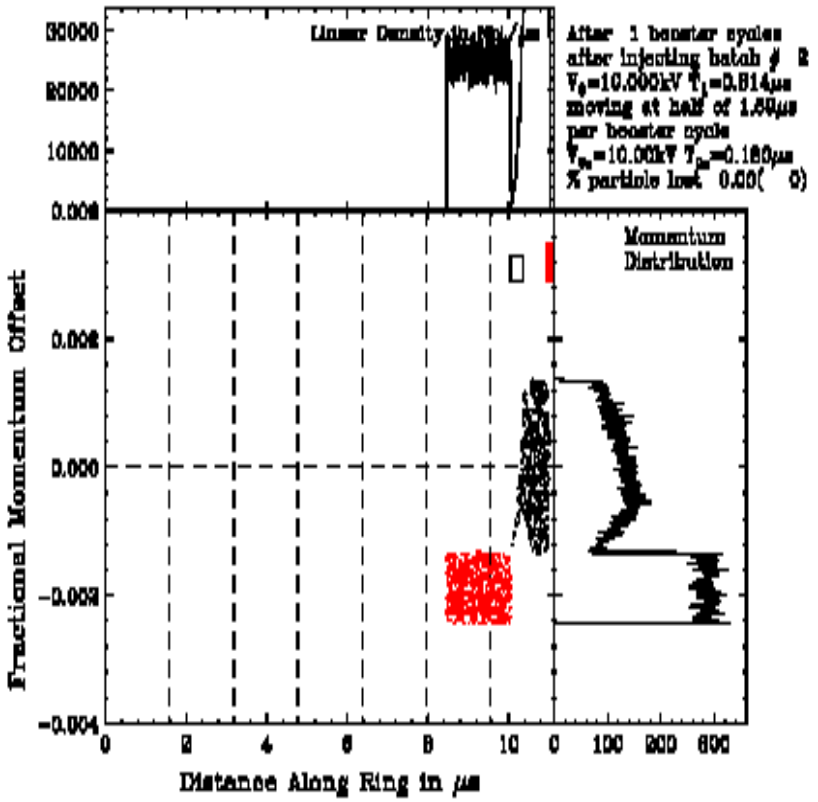


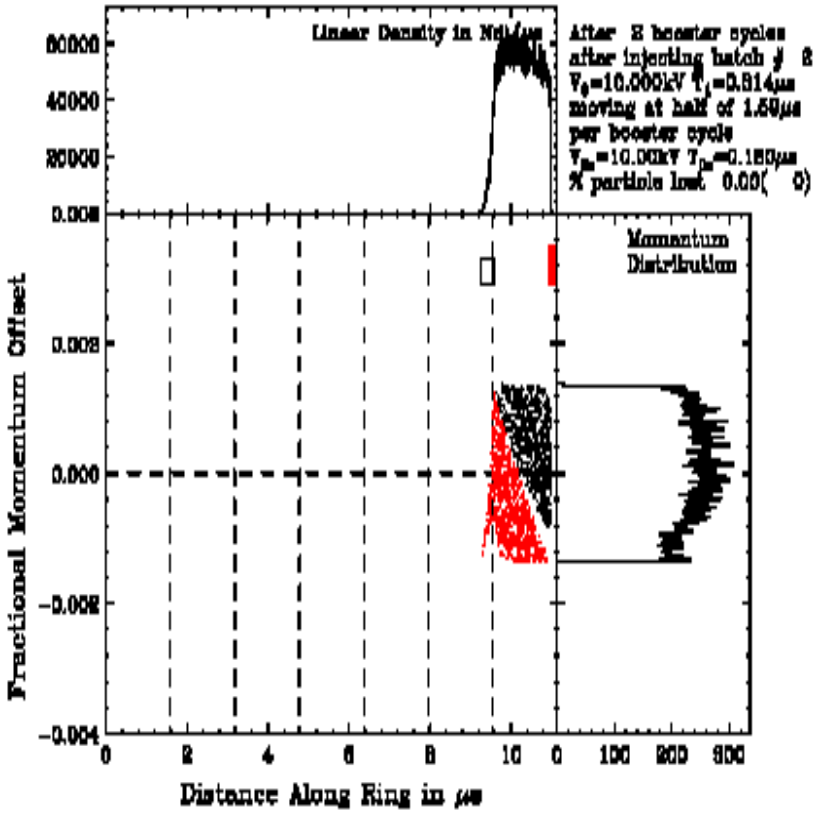


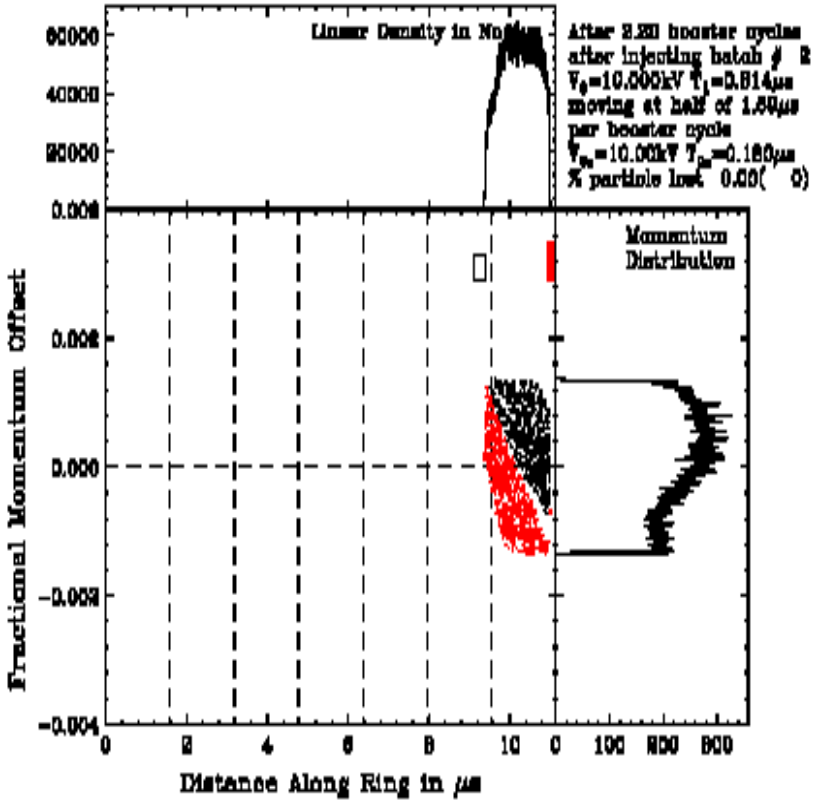
Injection Beam Off-Axis
(2-batch stacking, courtesy K-Y. Ng)





2-Batch Stacking
(cont…)





Barrier RF Stacking *vs.* Slip Stacking

- One main advantage of barrier RF stacking is smaller beam loading effect thanks to lower peak beam current
- Another "advantage" is that we didn't know much about this method and have never tried. (By contrast, we already know how hard slip stacking is.)

Key Issue

- Booster beam must have a small $\Delta p/p$ to start with (required ΔE about ± 6 MeV)
- This means one has to control the instability of the Booster beam by means of: (a) longitudinal damper, (b) RF frequency modulation, and to perform a bunch rotation prior to extraction

Hardware

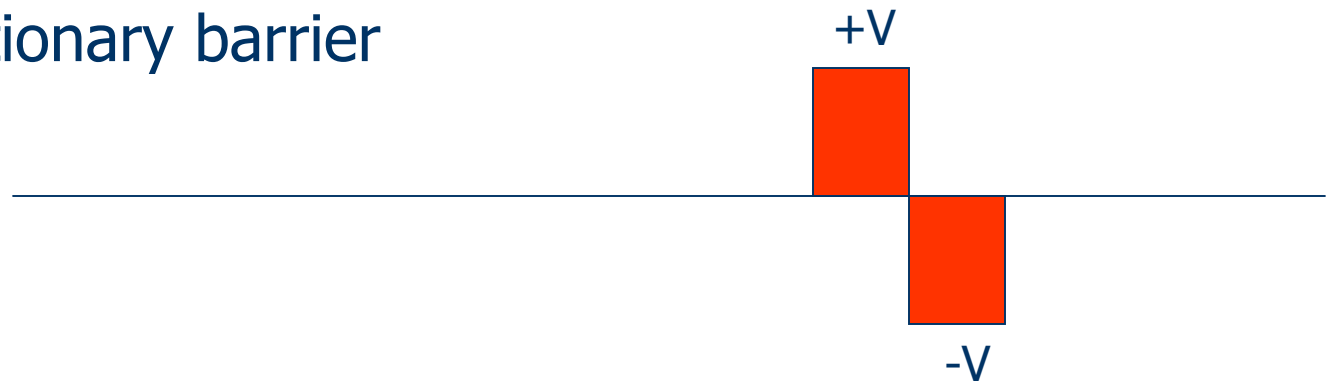
- Task: To build a $\pm$ 6 kV wideband RF system (i.e, the barrier RF) using Finemet cavities and high voltage fast switches
- Cavity: Based on the design of an RF chopper that was built by a Fermilab-KEK collaboration via a US-Japan Accord. Hitachi Metals Ltd. (Japan) will supply the Finemet cores

Hardware (cont…)

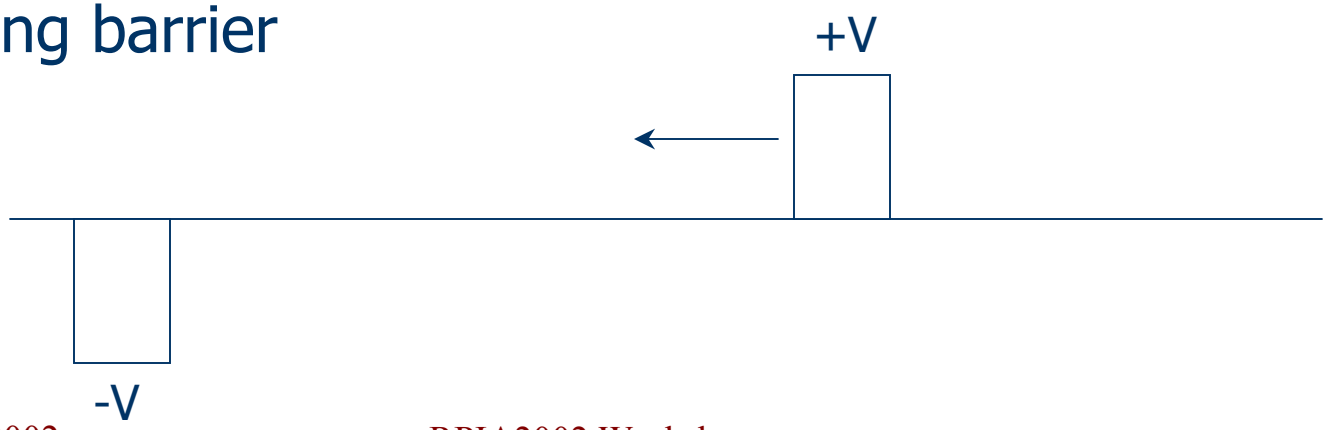
- Switch circuit: Also based on the design of the RF chopper. Behlke Co. (Germany) will supply the switches (solid state HTS series).
- However, there is an important difference between the chopper circuit and the barrier RF circuit. The former uses a pair of +V and -V pulses. The latter has two types. One of them requires a zero-voltage gap between +V and -V pulses. Therefore, the circuit must be modified. (No good design yet; Help welcome)

Two Types of Barrier

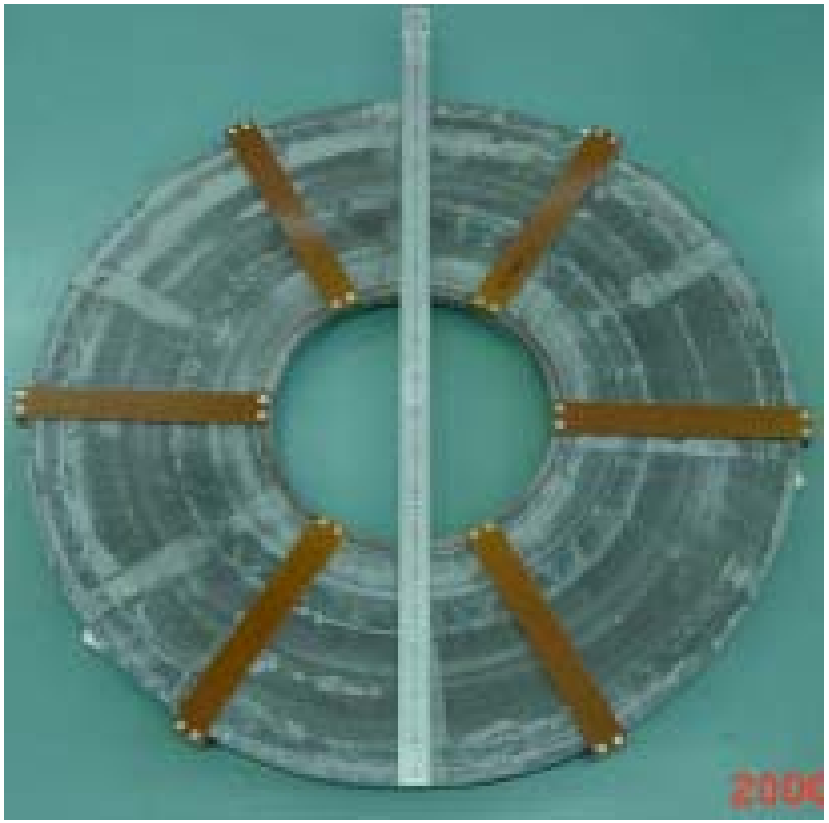
Stationary barrier



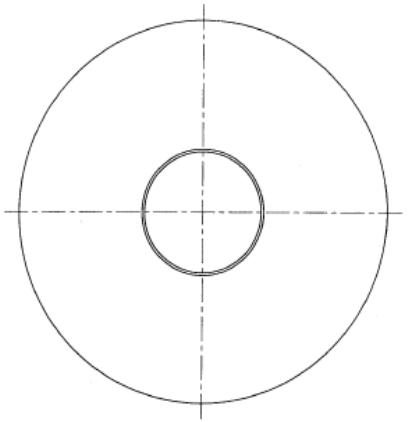
Moving barrier

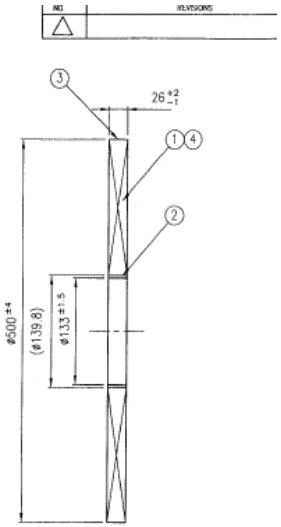


Finemet Core



DIMENSIONS
外観寸法

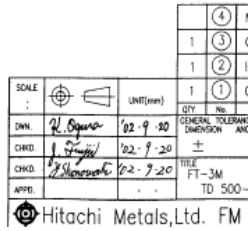




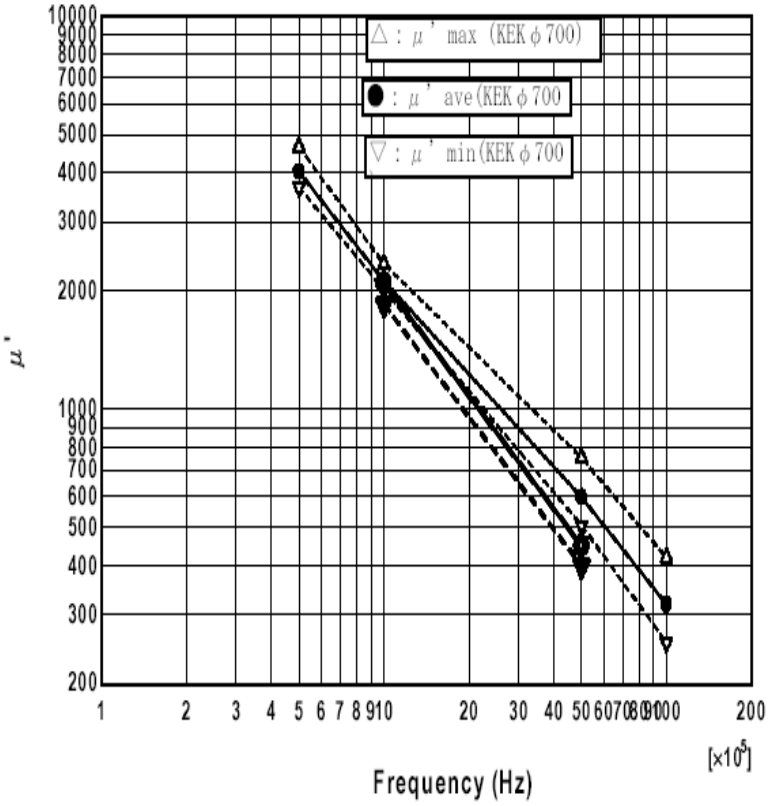
ELECTRICAL CHARACTERISTICS
電気特性

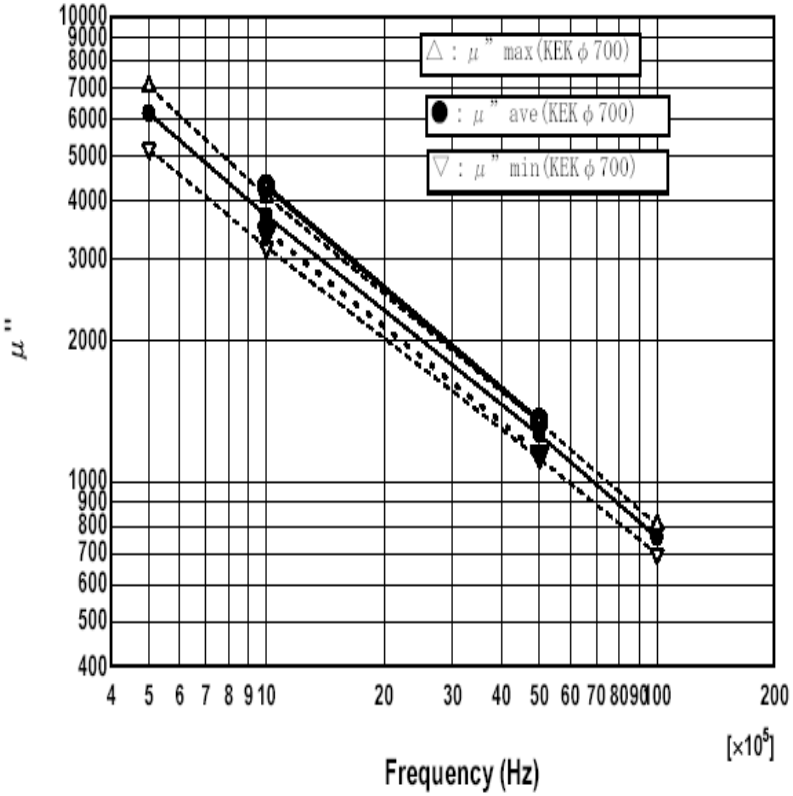
	Frequency	1MHz	5MHz
COMPLEX PERMEABILITY 複素透磁率	μ'	≥1700	≥350
	μ''	≥3000	≥1000

EQUIPEMENT :LCR METER HP-4284A or EQUIVALENT
CONDITION :0.5Vrms
MEASURING MODE: SERIES MODE

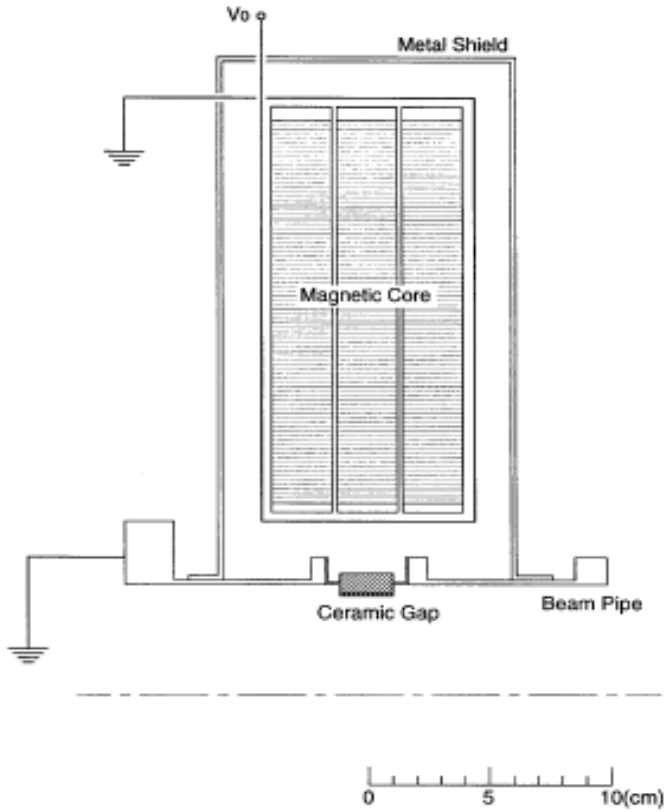


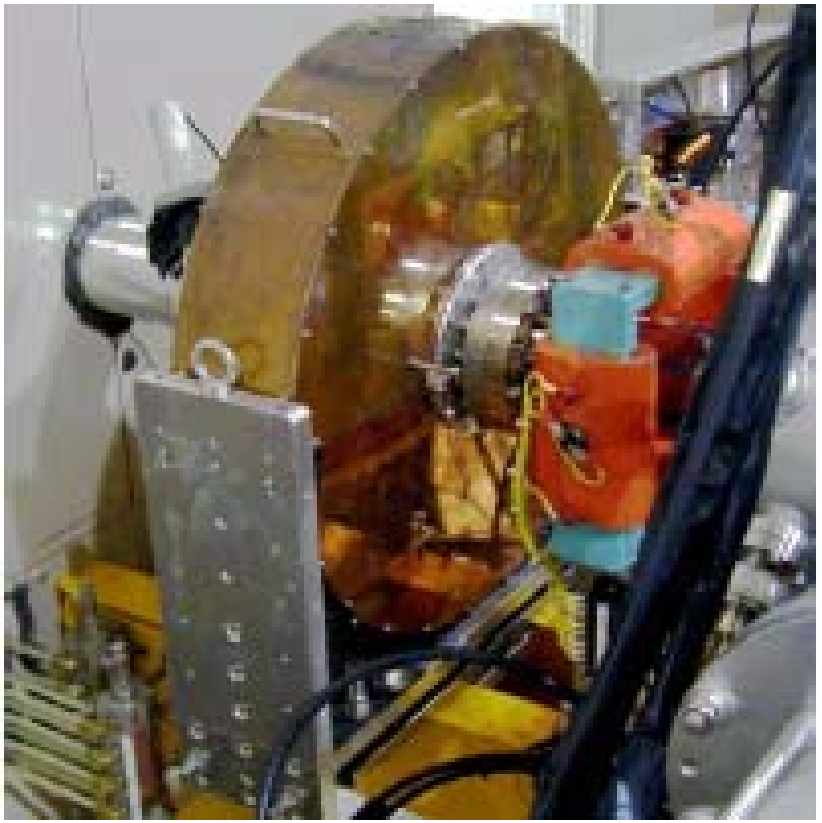
Finemet Core (cont…)



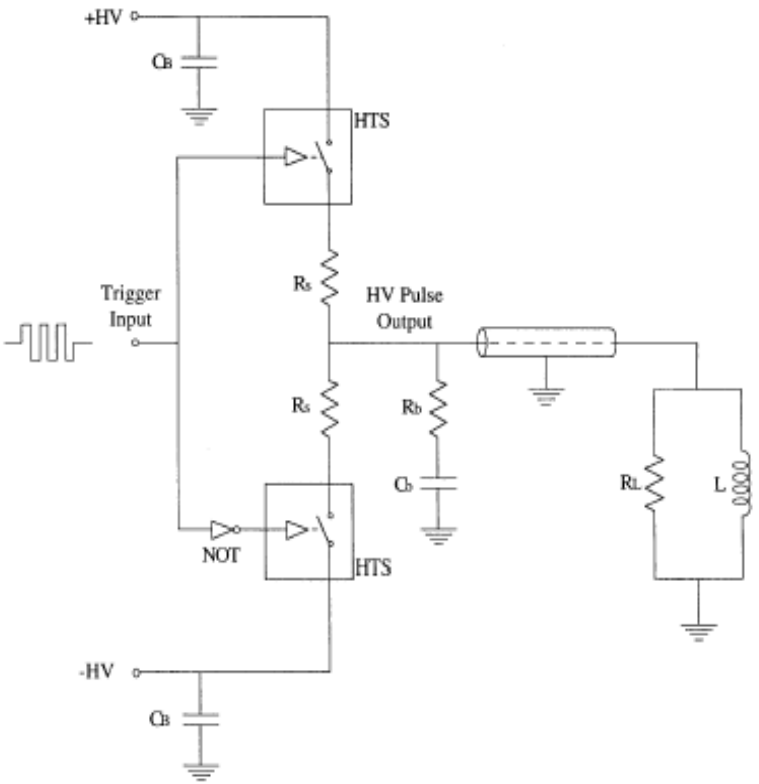


Finemet Cavity as a Chopper
(installed on the linac of HIMAC in Chiba)



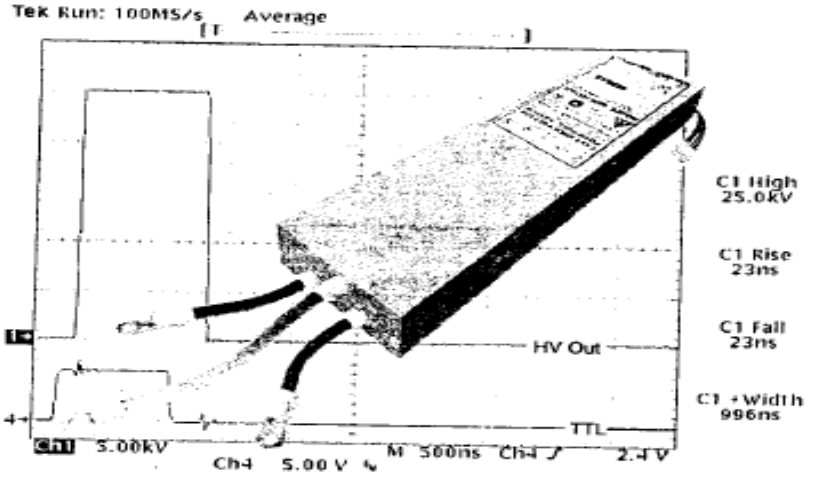


High Voltage Fast Switch



HTS 161-06-GSM 2x16kV / 60A

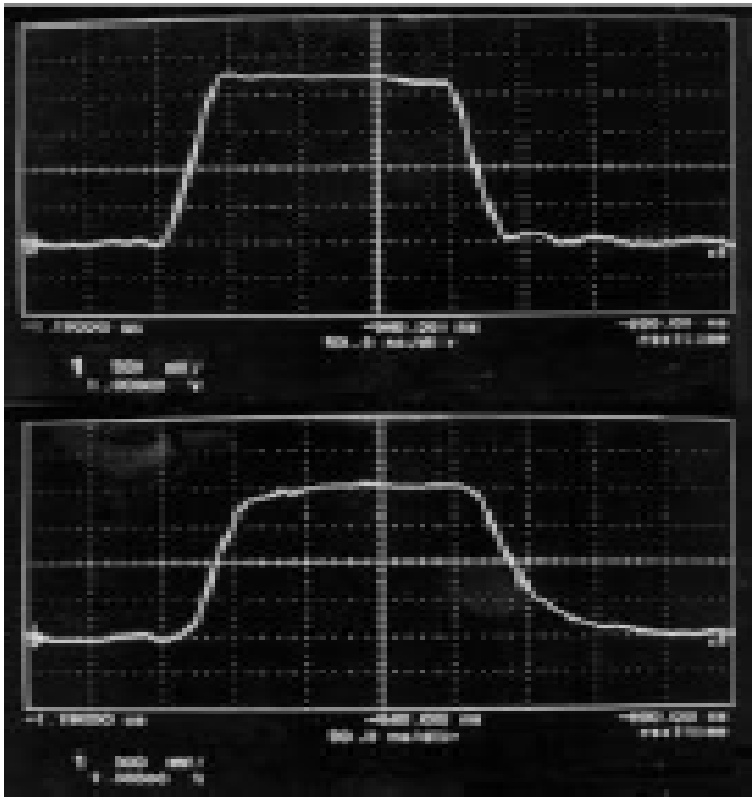
HTS 301-03-GSM 2x30kV / 30A

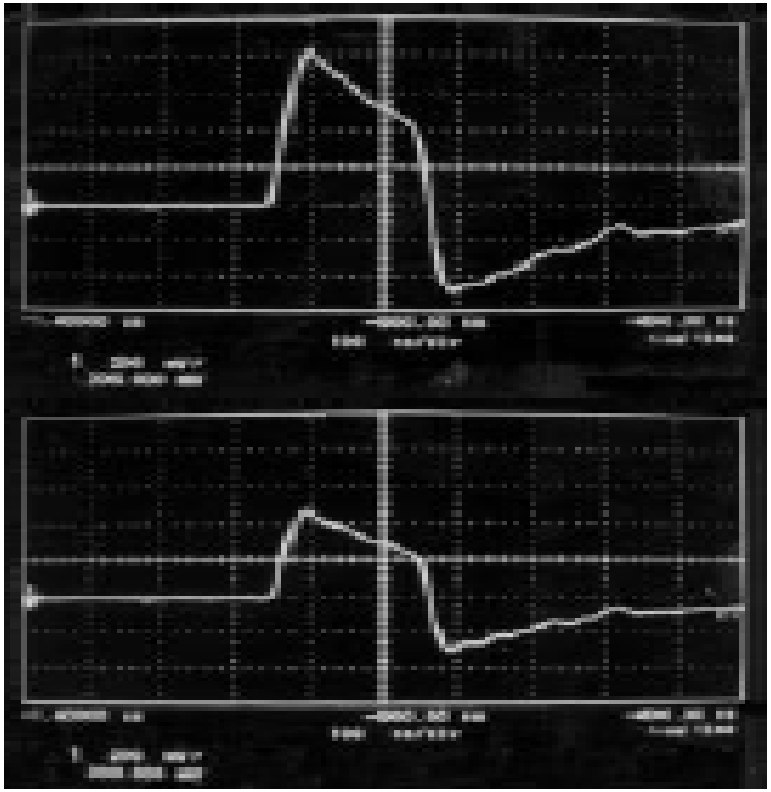


- Fast transition times, rise time and fall time ~20 ns
- Variable pulse width from 200 ns to infinity
- No pulse droop and very low ripple on the pulse top
- No working resistor power, small buffer capacitors

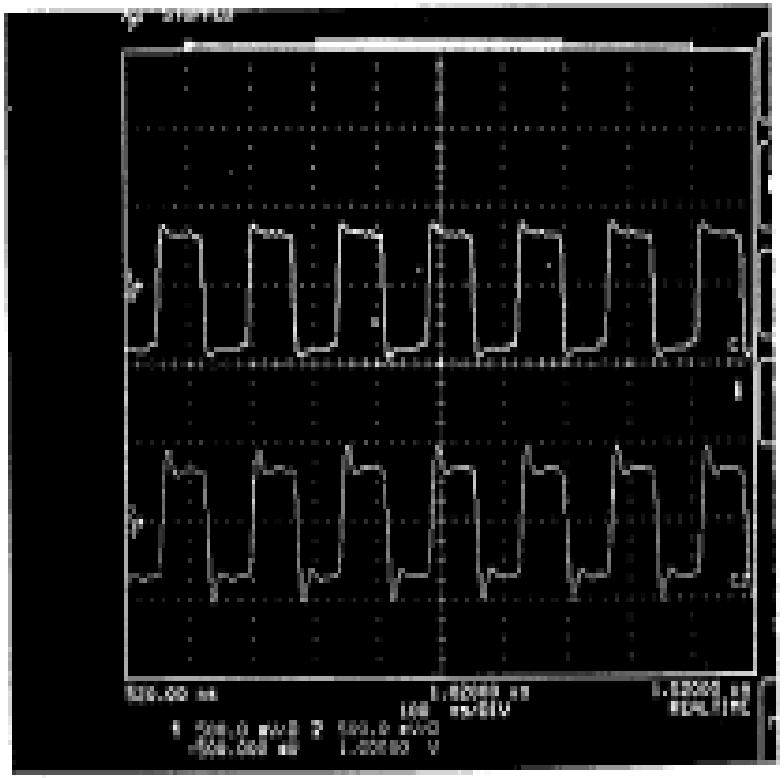
PUSH-PULL - Patented - Made in Germany MOSFET TECHNOLOGY

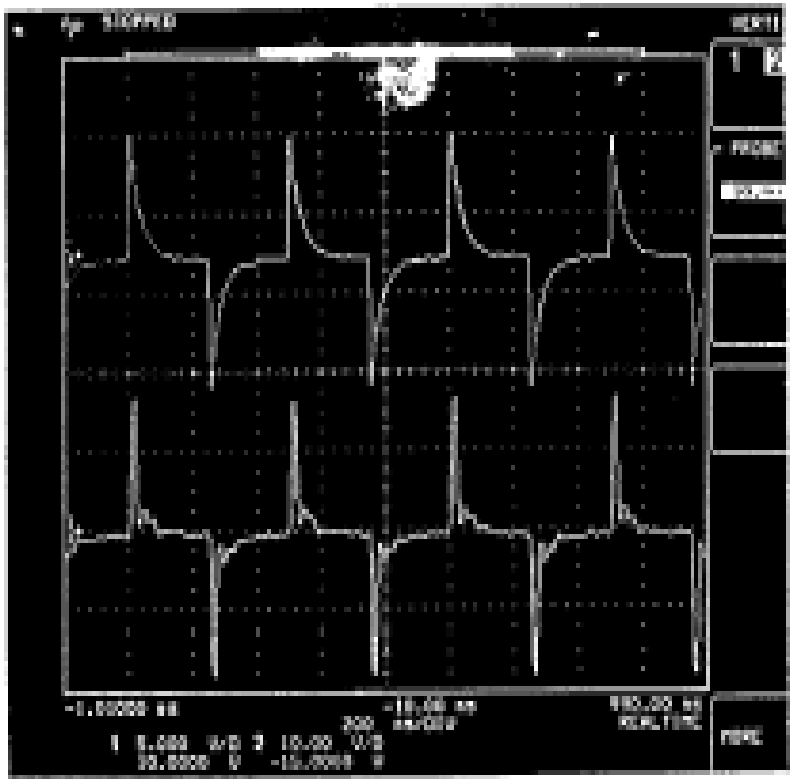
Finemet *vs.* Ferrite (4M2)





Finemet *vs.* Ferrite (4M2) (cont…)





Finemet Core Specs

- OD = 500 mm
- ID = 139.8 mm
- t = 25 mm
- Stainless steel mandrel OD = 139.8 mm
- Stainless steel mandrel ID = 133 mm
- t (mandrel) = 3.4 mm
- Inductance = 56 μH (per core)
- Resistance = 190 Ω (per core)

Switch Specs

- Operation peak voltage = $\pm$ 6 kV
- Operation peak current = 13 A
- HTS 161-06-GSM switch specs:
  - Max peak voltage = $\pm$ 2 x 8 kV
  - Max peak current = 2 x 60 A
  - Max burst frequency = 2 MHz
  - Rise and fall time = 20 ns
  - Min pulse width = 200 ns
  - Min pulse spacing = 400 ns

Summary

- Barrier RF for beam stacking is another application of induction devices in accelerators
- Unlike an acceleration RF, the barrier RF has following features: high peak voltage, high peak current, burst mode operation, low duty factor
- Finemet cores and HTS switches can meet the requirements
- A barrier RF system is being built at Fermilab

Questions?